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EFFECT OF CHANGES IN THE TIME VARIABLES IN MEMORIZING, TOGETHER WITH SOME DISCUSSION OF THE TECHNIQUE OF MEMORY EXPERIMENTATION.

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(With the co-operation of Supt. W. H. Sanders and Supt. F. A. Herrington.)

The effect of changes in the different rate variables in memorizing has been the subject for occasional investigation in the Psychological Laboratory of Indiana University since 1894-5, beginning at that time with the preparation of a Master's thesis by Supt. Sanders on the effect of different rates of reading lists of associable and dyssociable words and letters upon their retention and reproduction by auditors. The following year, with a view to extending the investigation to impressions received through the eye, and with a view also to securing apparatus of general utility for memory experiments, the writer designed the compound interrupter and exposure drum, figured and described further on. With this apparatus several studies were begun at different times, but none completed till Supt. Herrington made use of it in the preparation of a Master's thesis, in 1903-4, dealing with the effect of varying, in the learning of nonsense syllables, the duration of exposure of each syllable, the intervals between syllables, and the intermission between readings of series of syllables.

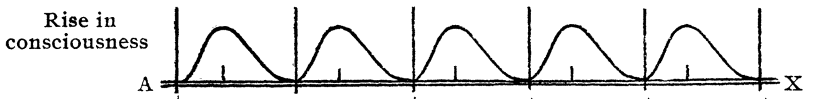
The points of special interest in the investigation have been partly technical and psychological and partly educational. The study of the rate variables in memorizing is, of course, a direct study of certain elements in the technique of experimentation in this field. To avoid the possible disturbing influence of these elements, experimenters have usually endeavored to keep them constant throughout an investigation; the study of their effects should reveal the significance of variations in them and also under what conditions the best experimental results may be expected. The apparatus required must not simply be serviceable for ordinary experimentation, but must, in addition, be adjustable with regard to the variables to be studied, so that what will serve for this purpose will serve for most, if not all, others in which comparable materials and methods are employed.

With regard to the psychological aspects of the problem, it may be said to be a study, on the one hand, of the degree of possible adjustment or adaptation to the different rate variables; and, on the other hand, to be a study of the various mental effects of changes in these variables. The wide range of possible adjustment of the mental processes involved, and the individual differences, are as remarkable in this as in most other lines. But adaptation is not complete and uniform for all rates; and the character, permanence, and economy of the work done under the different conditions is a matter of practical importance. Perhaps of chief interest, however, are the inferences suggested by the results as to certain fundamental modes of mental activity, partly apperceptive and partly retentive and reproductive, especially as to the probable subconscious adjustments that occur with the passage of time.

The solution of these psychological questions will aid in the analytic study of the pedagogical aspects of the problem. While the instinctive adaptation of both pupils and teachers, together with existing pedagogical precepts and traditions, has already contributed much to the elucidation of the subject, yet laboratory studies and practical tests in schools will be of service in the analysis of the causal factors, which common experience usually cannot with sufficient certainty accomplish. Moreover, personal differences, the pressure of work, and the common pedagogical illusion that what is easy for the teacher will be so for the pupils are liable to mislead the judgment as to the most advantageous rate of work. One cannot visit schools without receiving the impression that the rate of work of pupils varies considerably in different classrooms, and that the best rate is exceeded in some and not attained in others. Particularly is there danger that the rate will not be sufficiently adjusted for the different degrees of difficulty of the subject matter. The rate of work in many European schools, especially those under government control, seems often very severe and rapid, due, perhaps, in part to extensive programmes of study, and in part to the adoption of a rigorous class management, almost military in character. Whether average differences in the rate of work in different countries is sufficiently great and demonstrably due to permanent, temperamental causes so as to make it significant to speak of national types or differences cannot be regarded as definitely established, though statements with such implications are often made. At any rate, personal differences of this kind within a given country are probably much the greater.

In the analysis and formulation of the problem several distinctions must be noted. Mental states are of many different kinds and succeed each other at rates varying much according

to circumstances. The train of ideas which makes up the stuff to be remembered may take its course with or without immediate external suggestion and guidance. In the experiments here reported the succession of mental states was suggested by series of letters, nonsense syllables, associable, and dyssociable words, presented at certain definite rates. The rates of these external series, especially those for the eye, may be made quite accurate; but the corresponding mental series can only be made approximately as definite. The matter may be represented as follows:



Letters,	l	f	k	p	m
Nonsense syllables,	mak	tuj	pif	nox	vol
Unconnected words,	horse	bricks	solder	acorns	string
Associable words,	paper	writing	compose	position	work

Part AB of the imaginary time line AX is designed to represent the external duration of the impression; in the case of vision, for example, its visibility. Part BC represents the vacant interval between the disappearance of one impression and the presentation of its successor. The series of impressions may have been a series of any one of the different kinds of objects represented in the columns below the time line. The curve in the space above the time line is meant to suggest the rise and fading away of the idea in consciousness. In the case of associable ideas we may imagine a back reference from one idea to its predecessor that will connect and intensify them both.

A question of special interest but also of special difficulty is that regarding the nature of the connection established between successive members of the series, the answer to which can only be attempted by certain neurological speculations. Even the general form of the connection has only partly been made out; and it is to the solution of the latter problem that the numerous experimental investigations, beginning with that of Ebbinghaus, have in the last twenty-five years aimed to contribute. Ebbinghaus found that the associative bond extended not only

from one syllable to the next succeeding in the series learned, but measurably also as far as the ninth down in the list and also to some distance backwards. He ascertained that the strength of the connection decreased inversely as the logarithm of the time, as measured by the number of readings saved in relearning nonsense syllable series in the course of a month. A similar logarithmic law was found by Wolfe to hold for the decrease in the distinctness of the memory of a tone within the short period of a minute, as measured every few seconds by the ability to discriminate it from another nearly like it, though it must be noted as an exception that the tones were most easily discriminated from one another when the interval between them was about two seconds, which corresponds with the interval Dwelschauvers found most favorable for the adjustment of the attention in reaction time. Müller and Schumann have demonstrated that the associative bond between two syllables of a foot in rhythmic reading is stronger than the bond between adjacent syllables of different feet. Interference effects have been shown to develop in the formation of new modes of reaction for the same sensory material. Müller and Pilzecker have demonstrated with the aid of a new method that, other things being equal, old associations function more slowly than the more recent. The strength of an association varies, besides, with several other factors such as the condition of vigor or fatigue and the rate and mode of learning, which, as far as they concern the experiments here reported, will be considered in connection with their presentation.

The different characteristics of the associative bond are no doubt present in the ordinary operations of memory, though most of them are only to be definitely ascertained by means of experiments. What is on the surface and may be seen within any short period of observation are such facts as are described by the so-called laws of association: contiguity and relation, together with vividness, frequency, recency and the number of repetitions as determining the strength of the association. Inferences from experiments and pathological observations have suggested with more or less probability, besides these, certain less easily discernible factors, many of which will have to be considered in the endeavor to account for the experimental results presented. Thus, Professor Burnham infers from cases of retroactive amnesia that "in normal memory a process of organization is continually going on—a physical process of organization and a psychological process of repetition and association. In order that ideas may become a part of permanent memory, time must elapse for the processes of organization to be completed." If true, this theory would play an important part in the explanation of the results of this

investigation. In the cases of retroactive amnesia described by him, the amnesia extends not only to the facts of the accident that brought it about, such as the fall from a horse or other injury, but also to the events preceding the accident by from a few seconds to perhaps several hours. The explanation proposed for this, which is the basis for the more general inference quoted, is that the shock interrupted a certain organizing process of the mind, which is active not only at the time of receiving the impressions but for some time afterwards and is necessary for their retention and recall.

Therefore, while it is possible to make each member of an external series of impressions occupy a definite time and be succeeded by another after a definite interval, and to make conscious attention to the impressions approximately parallel with this, there is the possibility of a more continuous nervous activity, which, in spite of the apparent parallelism of the objective and the subjective series, can make the results with the slower rates better. In view of this possible persistence of nervous activity, it will be necessary not to imply, in formulating the problem, as the study of the effects of changes in the time variables in memorizing, more than that conscious attention to the series approximately corresponds with the rate of the external series.

II.

The methods employed in memory investigations may be placed in three classes, namely, those which involve the complete memorizing and reproduction; those which involve only the partial memorizing and reproduction of the items studied, and those which measure the rate of functioning of the association. In the first class belongs the original memorizing method of Ebbinghaus, in accordance with which a series of nonsense syllables was repeated till a perfect repetition by heart was obtained. The number of readings or repetitions needed was used to measure either the increased difficulty of learning with increased length of series, or, in the case of series once learned, to measure after certain intervals the strength of the associations still remaining by the saving effected in relearning, in comparison with the number of repetitions required for a new series of the same length. Throughout this paper this method will be called the complete memorizing method. In this class belongs also one form of the memory span test, namely, that in which the limits of the span are ascertained by making successive additions to or subtractions from a list of items read or shown to the subject till the maximum number that can be retained after being once heard or seen is found.

In the second form of the memory span test, which is the one

usually employed in simultaneous experiments with a large number of individuals, a slightly longer list of items than can be remembered after a single presentation is used and the relative efficiency measured inversely by the errors made. The actual "memory span" is not ascertained but merely the relative efficiency under the same conditions. This experiment is the best known of those which belong to the second group. The reproduction of what is memorized is partial and must be so, since differences in records are only possible when errors are present. The method of right associates (*Treffermethode*), developed by G. E. Müller and Pilzecker in the psychological laboratory at Göttingen and first described in a paper by Jost, in 1897, also belongs in this class. A series of items like nonsense syllables is repeated a certain number of times and, after an interval, alternate ones are shown singly to the subject and he is required to recall the one immediately succeeding or preceding, as the problem may require. Usually the syllable series is learned by reading in trochaic rhythm; and the test of the strength of the association at some subsequent time is made by presenting one of the syllables of each foot to the subject and requiring him to recall the other. The number rightly recalled is taken as the measure. Additional information regarding the value of the associations is sometimes obtained by measuring with the aid of the chronoscope the length of time required for each recall. The prompting method of Ebbinghaus is still another method to be classified in this second list. In this, too, not enough readings are employed to enable the subject to reproduce the material completely; the number of times he must be prompted to enable him to do so is the inverse measure of the condition of the associations. The methods of the second class so far described are, of course, easier and do not require so much time in execution as would the memorizing of series of the same length for complete reproduction, with the possible exception of the method of right associates when the time of the associations is measured. This element of greater ease is still more noticeable in another method belonging to this class, which may be called the recognition method. An account of the employment of it is found in an article by Hegelmaier upon memory for length of lines, an experimental study made in Vierordt's laboratory about 1852. It has since been employed by H. K. Wolfe in experiments upon memory for tones and by many others in the study of memory for qualities and intensities of sensations. The method is the same as the method of "right and wrong cases" in experiments for the Weber law, the interval between presenting the standard and the comparison being varied, if the purpose of the experiment is to ascertain the rate of forgetting. More recently the recog-

nition method has been employed by Fritz Reuther with complex materials. In his experiments he required the subject to read series of four place numbers, which he then showed him later according to certain experimental plans to see how many he would recognize. The subject did not, of course, know that the second series was the same.

The writer has employed the method in the following form: A series of ten nonsense syllables were read once or more according to the problem; then a second series of twenty syllables was shown containing the first ten and ten others. The number of syllables the subject recognized under given conditions was taken as the measure of the strength of the associations. It is essential in the use of this method, as with others of its class, that only a part of the syllables shall be recognized. Figure 2 gives a sample of the material used.

FIGURE 2. PART I.

pub	kij	mag	qer	vum	sed	lif	hov	tol	jap

PART II.

tus	ziz	pub	sed	nur	vum	san	wav	jap	qer
gox	lif	tol	qif	hov	mag	lom	ket	kij	dul

The method employed by Miss Theodate L. Smith, in which a series of ten syllables or characters were exposed to view for twenty seconds for the subject to read as he pleased, with the requirement that he should write down all he could remember afterwards, belongs also in this class; as do the methods employed in the experiments reported in this paper.

In the third class may be placed the usual methods for determining the practice curve by measuring the improvement in speed, as, for example, was done by Bryan and Harter in the study of telegraphic language. Here, too, would be placed the method employed by the writer in the study of memory problems by the interference of associations. In both classes of experiments the rate of functioning is what is directly measured.

III.

The experimental technique in the use of these methods also goes back to the work of Ebbinghaus, who formulated some of the chief requirements. To secure uniform unconnected material for his experiments, Ebbinghaus made use of nonsense syllable series. Müller and Schumann introduced a convenient plan for their construction and laid down certain rules for securing greater homogeneity, so as to make them "normal" or "extra normal," in this developing a procedure which Ebbinghaus had discarded in favor of leaving the character of the

syllables wholly to chance. To be "normal" all initial consonants, all middle vowels, and all final consonants respectively in any given series must be different, as far as possible. The initial consonant of the first and the final consonant of the second syllable of one of the trochaic feet into which the series is divided in reading must not be the same; and two or more successive syllables must not form well-known words or phrases. To be "extra normal" no two syllables used on the same day shall have two letters the same. In constructing series small cards with initial consonants are placed in one box, cards with the middle vowels in another, and cards with the end consonants in a third. A syllable is made by taking by chance a letter from each of the boxes in the order mentioned. When a sufficient number of syllables for a series has been secured, the cards used are put back into their respective boxes and the procedure repeated for other series. After this, what needs to be done to make the series "normal," can usually be done by shifting one or two syllables; the "extra-normal," however, may require the construction of new syllables.

To secure the uniformity necessary for experimental purposes in the work of memorizing itself, Ebbinghaus read, repeated what he could, read from the point of hesitation, and continued reading and repeating in this way, all at the uniform rate of 150 syllables per minute, till he was able to repeat the whole series by heart. The rate was secured by timing the reading, in the early experiments, by the strokes of a metronome, and in the later, by the ticks of a watch. The syllable series was written on a sheet of paper, and in reading several syllables might be seen at once. The effort to maintain a certain rate by aid of an external standard is a source of strain and distraction, especially at first; moreover, the possibility of seeing several syllables at once might introduce an error in the study of various values in successive association. Müller and Schumann, therefore, in taking up the study of memory problems by the Ebbinghaus method, endeavored to avoid these difficulties by placing the syllable lists, written in a vertical order, on the horizontal drum of a kymograph, before which they arranged a screen with an opening so that only one syllable could be seen at a time. This plan has been employed not only in the extensive and important studies made in Professor Müller's laboratory at Göttingen, but in studies made elsewhere, as at Würzburg and Chicago. For changes in the duration of visibility of the syllables, or of the intervals between them, or of the rests between series of syllables, it is evidently inconvenient and not free from the introduction of other variables than the one studied. For example, if the rate of presentation of the syllables is varied by changing the rate

of the drum, the rate of motion of the syllable, as it goes before the eye, and so the time of its visibility, or else the distance it traverses, is altered. To change the rate of presentation of the syllables and yet keep the time of visibility the same, would require keeping the kymograph at the same speed and respacing the syllables. The authors call attention to another difficulty, namely, that watching the movement of the drum and syllables gives rise to eye strain and even dizziness, which one of their subjects suggested might be remedied by having the presentation of the syllables made step-fashion. Published accounts of apparatus by which this might be done have not, however, appeared till recently. The latest, that by Dr. Wirth, seems to differ from the first, that of Randsburg, chiefly in being so planned as to be nearly noiseless in its operation. It consists essentially of a disc or short drum moved by a weight, but made to move step-fashion by an escapement, which is operated electrically by a metronome. With the disc, the items to be learned are written in sectors, the disc moving forward a sector at a time and each sector being one-sixtieth of the whole area. These pieces of apparatus leave the syllable stationary while it is being observed but do not provide means for varing the duration of visibility independently of the general variation in the rate of succession or for the convenient adjustment of the intervals between series. In these respects the apparatus used in our experiments and described below has the advantage.

Figure 3 reproduces a sketch of the compound interrupter, or system of pendulums, by which the intervals between syllables and the duration of visibility of each syllable is regulated, as far as need be, independently one of the other. The visibility is regulated by the small pendulum at the right, P^3. P^3 does not swing independently of the other two pendulums, P^1 and P^2. At each extremity of its swing there is an electro magnet, one of which shows in the figure. It swings from one to the other only when the current in the magnet that holds it is broken. When the current in the magnet at one end is broken, it is made simultaneously in the magnet at the other extreme, so that the pendulum, when it reaches this, is caught and held till the current in that is in turn broken. The current may be made or broken in these two magnets by either of the two large pendulums according to the connections made. The change occurs when the large pendulum, with which the small pendulum magnets are connected, swings past its centre and therefore regularly at the beginning of each half swing. The half swing of the large pendulums gives the intervals between the syllables, the swing of the little pendulum gives the duration of visibility, which can, of course, remain the same

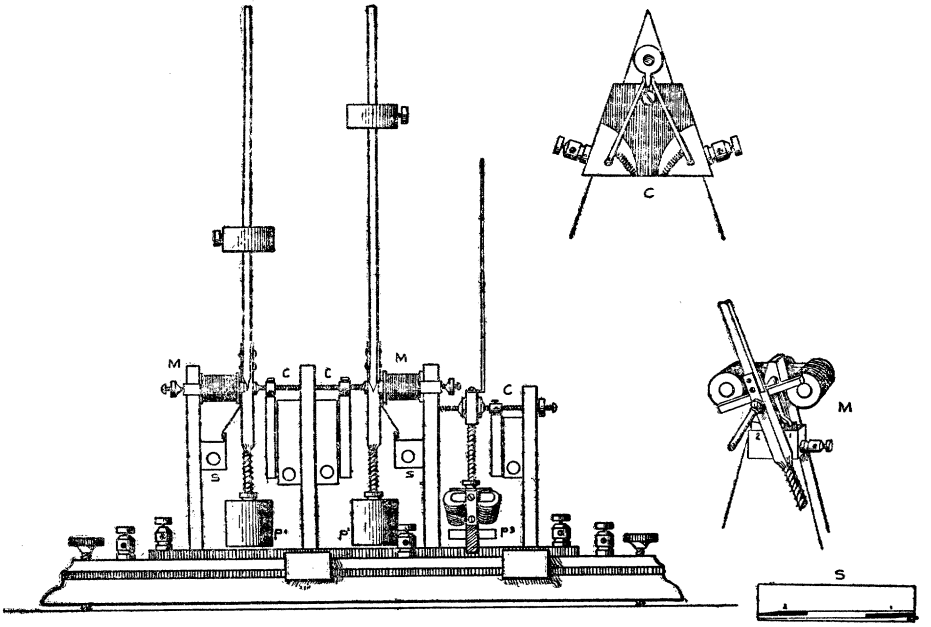


FIGURE 3. COMPOUND INTERRUPTER.

with different periods of the larger pendulums, or be varied while the total interval between the syllables remains the same.

The large pendulums are kept in motion by being parts of the oscillating motors (M). They receive a slight impetus when nearing the vertical in their swing each way. The commutator (S) is so arranged that the contact spring bears now on one side, now on the other, according to the direction of the swing. The heavy lines of (S) are metallic contact surfaces.

For practically all experiments likely to be made, only one of the large pendulums would be needed, so that the interrupter could to that extent be simplified. It would then consist of one large and one small pendulum. The electrical connections with the escapement would be correspondingly reduced in number. In this respect it is now so arranged that by the switch shown in Figure 4 either of the large pendulums can be made to operate the escapement in immediate succession, the small pendulum working with one or the other as may be required. This arrangement was especially made so that the subject, according to a variation of the Ebbinghaus method, might read the syllables at one rate and repeat them at a slower rate, but be able, as soon as he failed in repeating, to

throw in the more rapid rate, at any time in the series, for further reading. However, no use of it for this purpose has been made and most forms of experiment would not require it, so that the device for this particular purpose could very well be omitted. As far as known to the writer, this piece of apparatus for combined intervals is new in principle and design and may possibly prove to be of some service.

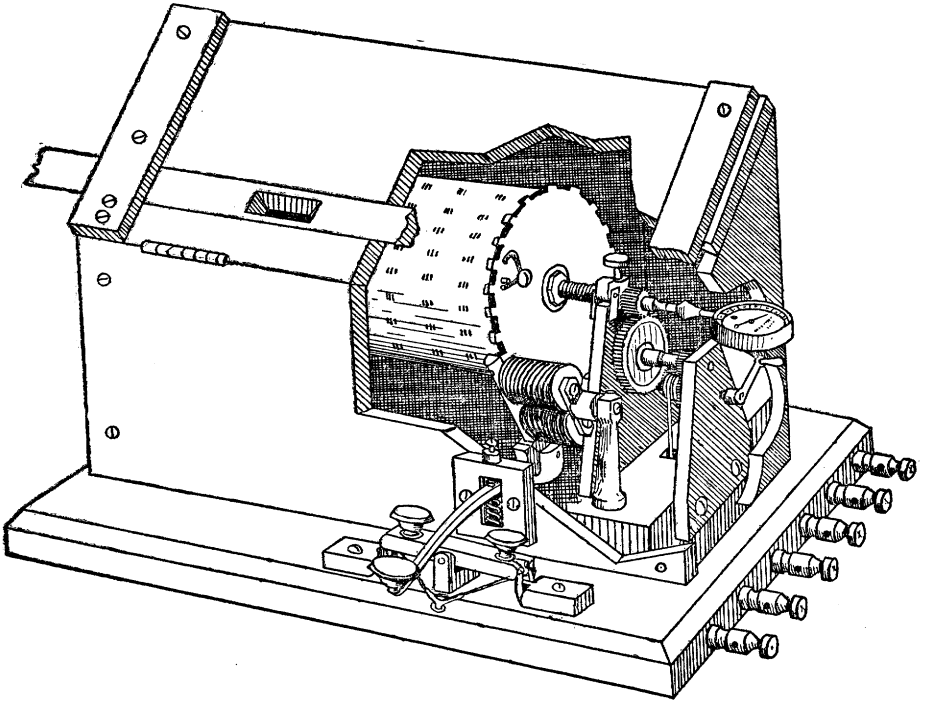


FIGURE 4. EXPOSURE DRUM.

Figure 4 gives a picture of the exposure drum and escapement. The drum is about 16.5 cm. long and 9 cm. in diameter. Since it must act as quickly and with as little shock as possible, a point of special importance is to make it very light. This one has aluminum ends and a thin aluminum cylinder. For the cylinder a heavy paper was at one time used, but the aluminum seems better. The use of a skeleton steel end for the one with the cogs would be an improvement. One thing to be noted is that by the pressure of the lever the escapement is thrown out of action so that the drum flies around to the starting point, being there arrested by the two-pronged spring

screwed to the end of the drum, the curved prong arresting the drum gently, the straight one placing it in position. As soon as the end of a series is reached, it is possible to make the interval before beginning reading it again whatever may be desired, without the need of waiting till the drum, by its interrupted motion, brings one to the beginning.

The noise is reduced somewhat by mounting the drum solidly on a rather heavy iron base and by placing the entire apparatus on a stone foundation. But even so, the escapement works with a sharp, though not a reverberating click. However, the blows of the cogs on the escapement are synchronous with the presentation of the syllables and distract the attention but little, since there is no requirement that they shall be attended to or followed. The effect is somewhat the same as would be produced by accompanying the oral reading of the syllables by a synchronous tapping on the table.

One part of the apparatus does not show in the sketch, namely, the part needed in the employment of the recognition method described above. In this case it is necessary to have some means of recording what syllables are recognized. This record is made on a narrow strip on the left end of the drum by means of an electric marker. The use of other parts of the apparatus, such as the slide with opening for seeing the syllables and the rotation recorder at the right end, doubtless, need no explanation. One other thing, however, should be mentioned. No additional apparatus is needed in employing the method of right associates, except a chronoscope in case the time of recall is also to be measured. The pressure on the same key can simultaneously start the chronoscope and make the exposure of the syllable.

The drum was made of such a size that the vertical distances of the syllables, or the interlineage, corresponds to a fixed interlineage of a type-writer, by which all the syllable lists have been prepared.

IV.

As has been stated, the first experimental data were, however, not obtained with the aid of this apparatus but by oral presentation at different rates, the rate being controlled by a metronome. The chief experiment made by Supt. Sanders by this method comprises records obtained simultaneously from thirty students in the psychological laboratory, in May and June, 1895. The students had participated in laboratory practice throughout the academic year up to that time, so that the conditions were quite favorable. Two kinds of materials were used, namely, lists of ten associable words and lists of ten letters arranged in accidental order. Series of both kinds were

read on each day of experimentation according to a compensating programme, with intervals from word to word or letter to letter of 0, .5, 1, and 2 seconds. Each series was read once and the subjects were asked to write down as many as they could remember within a certain time beginning immediately after the reading. The average number of series of associable words and letters employed with each individual at each rate was 22.4 and 30.23, or 224 words and 302.3 letters respectively; giving a total of 6,720 words and 9,070 letters for the whole group at each rate, or a total of 20,160 words and 27,210 letters for all at all three rates. The errors made are classified as omissions, insertions, and mistakes of order. By omissions is meant the number of words or letters left out by the subject in reproducing a series, by insertions the number of words or letters put down by him that were not in the original series. The number of real mistakes of order cannot be counted exactly but it is probably approximately proportional to the number of changes that must be made to set the series right, and this is what has been counted and set down under the head of mistakes of order. The accuracy of reproduction is inversely as the number of errors; this must be kept in mind in the interpretation of the averages.

TABLE I.

	Associable Words.			*Letters.*		
Intervals between words.	0.5	1	2	0.5	1	2 seconds.
Omissions.	2686	1967	1286	2439	2362	2160
Insertions,	540	319	186	825	705	624
Mistakes of order.	209	167	134	735	801	703
Total.	3435	2453	1606	3999	3868	3487
Per cent. of whole number of words or letters.	51.12	36.5	23.9	44.09	42.65	38.44

To facilitate comparison of the changes with the different rates, Table II gives the distribution of errors at the different rates in per cents of the total number of errors of each kind.

The number of errors with the associable words is 37.17% of the whole number of words; the number of errors with the letters is 41.73% of the whole number of letters. In the case of the words, the omissions are 29.46%, the insertions 5.16% and the mistakes of order 2.53% of the whole number of words; and in the case of the letters the corresponding per cents are, 25.58, 7.92, and 8.45. The fact that there are relatively

TABLE II.

	Associable Words.			*Letters.*		
Intervals.	0.5	1	2	0.5	1	2 seconds.
Omissions.	45.23	33.12	21.65	35.04	33.93	31.03
Insertions.	51.67	30.53	17.8	38.26	32.73	28.97
Mistakes of order.	40.95	32.75	26.28	32.83	35.77	31.4
Total.	45.84	32.74	21.43	35.23	34.04	30.79

more insertions and especially mistakes of order with the letters than with the words, is doubtless due to the fact that the words make a series with an order determined by the associations, which is not generally true with the letters but only accidentally so when they happen to fall into a mnemonic scheme. That they would not be remembered so well in their order would naturally follow. The absence of definite, well known associations in the case of the letters, together with their small number and their being used over and over again would make one more liable than in the case of the words to make insertions of letters which should not be present.

What concerns us especially, however, is the striking difference in the relative distribution of errors in the two kinds of materials at the different rates. With the words the number of errors decreases to less than half as the intervals increase from 0.5 to 2 seconds. With the letters the decrease is relatively small, the change from 1 to 2 having somewhat greater effect than the change from 0.5 to 1 second. With neither kind of material do the different kinds of errors decrease in the same proportion. In both the decrease in the per cent. of insertions is greatest, in the per cent. of mistakes of order least of all.

The marked reduction of the errors with lengthening intervals in the case of the words can leave no doubt of the great effect of the interval. The reduction occurs with every individual and with regard to all kinds of errors, with a few exceptions in mistakes of order. The number of errors would be still further reduced if the intervals were made longer, for, if the connection between the words is carefully noted, all can usually be reproduced either forward or backward, even after a considerable period of time. Should the reduction in the number of errors continue at the same rate, as is probable, there would be only 10% errors if the longest interval were doubled; and, if the interval were then doubled again, nearly all would perhaps disappear.

In the case of the letters the reduction in the errors with in-

creasing intervals is relatively small and does not occur in every case but only with twenty-one of the thirty subjects, the rest either doing nearly equally well or slightly better with the more rapid rates.

After the tests were over, Supt. Sanders made a personal inquiry regarding the methods of memorizing by the different subjects, particularly as to whether mnemonic aids suggested themselves in learning the letters. He found that most of those who prefer the slower rates have a disposition to employ some grouping or association, while most of those who prefer the more rapid rates do not do so. It seemed probable, therefore, that the better records obtained with the letters at the slower rates were due to associative processes in this case as well as in the case of the words, and that, aside from this the mind can adapt itself to receiving simple unrelated impressions, like the letters nearly equally well at any of the rates employed, while the intervals have a high value with relatively complex and associable material. That this conclusion represents the most important comparative aspect of the two sets of experiments, seems clear. Whether it can be made to cover all the facts now known about this problem, will be considered later in connection with the discussion of subsequent experiments and the results of others.

In the case of the associable words the total number of errors make the following per cents of the whole number of words at the different rates; (0.5, 1, and 2 seconds), namely, 51.12, 36.5, and 23.9, giving 14.62 and 12.6 respectively as the amount of decrease from the shortest to the medium and from the medium to the longest interval. If we consider only the omissions, which are about four times as numerous as all the other errors put together, we find that the decrease from 0.5 to 1 is almost exactly as great as the decrease from 1 to 2, the omissions making the following per cents of the whole, 39.97, 29.27 and 19.14, and giving 10.7 and 10.13 as the differences. The decrease in the errors proceeds approximately in an arithmetical series, while the intervals increase in a geometrical series, the rate of decrease of the insertions being greater and that of mistakes of order less. The number of insertions at the fastest rate is disproportionately large, which may be due to indistinctness of enunciation by the experimenter or inattention on the part of the subject. As has been said, if the relations in the series had been clearly noted, nearly all of the words would have been recalled. The realization of meanings and the noting of relations between the words took place to some extent with the most rapid rate, to a much greater extent with the slowest rate, though it was even with this incomplete. The words represent complex, though familiar ideas and the

seeing of the relations between them depends upon and doubtless takes place directly in connection with the apprehension of the different meanings of the words. Moreover, if we assume that the amount recalled varies with the degree of association, we can state the result from this point of view as follows: *The acquisition and retention of a series of familiar associable words varies approximately as the logarithm of the interval at which the words are spoken, the shortest interval being that which barely permits a clear pronunciation.* The length of time before a given stage of association would be reached would vary with the individual and the material, but even within these limits the scope of this law, if we can so call it, may be very great. It is not unlikely that it would roughly represent the rate of acquisition of ideas from reading or oral communication; not that the intervals in this case would be between words, but rather between ideas suggested by significant words, phrases, and clauses. Seeing the relations between the words of these experimental series requires a realization of the meanings of words and the perceiving of relations, which is not unlike the process required for the apperception of discourse. According to this formula, acquisition is especially rapid in the first few moments, which accords with experience, since a speaker needs only to make a small difference in his rate of utterance to make himself either well or ill understood. With respect to this matter, however, individual differences are considerable, and the statement is only regarded as a rough expression of a general result. A preliminary experiment by Supt. Sanders with six persons gives some additional data. Two kinds of materials were used, namely, lists of ten associable words and lists of eight disconnected, or dyssociable words. There are 240 series for each of the six general averages, 40 being supplied by each subject. The intervals do not, in this case, make a geometrical progression, which must be kept in mind in considering how closely the averages follow the formula. The per cents in the the table below (the sums for all three kinds of errors) are of the total number of words for the different intervals.

	Associable Words.			*Disconnected Words.*		
Intervals.	.476	.715	1.43	.476	.715	1.43 sec.
Per cent. of errors.	63.4	51.04	35.45	66.7	56.8	45
Differences.	12.36	15.64		9.9	11.8	

To conform to the formula differences with the associable words should be in the ratio 3 : 5. The actual ratio is 3 : 4,

which shows considerable divergence. There was some, but not so great, a difference in the same direction in the preceding experiment. This may be the normal deviation, though there is some reason for believing that it is due to the development of insertions from causes that would not be a part of the process to which the formula is supposed to apply. Such would be insertions due to misconceptions of words indistinctly spoken, which would be liable to occur chiefly at the most rapid rate. The misconception takes its place as one of the number of items the subject can remember and so will often give rise to an omission as well as to an insertion, in this case, counting double in the totals. Supt. Sanders collected a number of instances of still another type of insertion that occurs chiefly with the rapid rate. In this case the subject, instead of remembering the word spoken, remembers a suggested word.

Word pronounced.	Word written.	Word pronounced.	Word written.
lisp	tongue	music	songs
dual	double	fire	flames
silent	quiet	classes	scholars
trees	forest	sound	noise
son	boy		

With regard to the disconnected words, it might have been supposed that the effect of the intervals with them would correspond rather with the effect on the letters than with the effect on the associable words, but the reverse is true. It will be seen, however, that the influence of the intervals in the case of the disconnected words is only about two-thirds as great, which would place them in this respect between the associable words and the letters. As in the case of the associable series, the words represent familiar, but rather complex, ideas, and besides, they may not be wholly unassociable, but merely dyssociable. The explanation of the effect is therefore probably the same in both cases, though the value of the longer intervals with the disconnected words is probably to be found in the more complete apprehension of the individual words rather than of their connection with each other.

V.

In the experiments made by Mr. Herrington in 1903-4, with the aid of the apparatus described in Section III, only one kind of material was used, namely, nonsense syllables. In this case a greater degree of precision with regard to the intervals is possible; and the schedule of experiments was arranged to make use of this advantage so as to ascertain the effect of changes in all the elementary time variables. It was, therefore, partly a study of the elementary factors of technique and

partly a study of the psychological problems involved. The experiments of Sanders were addressed to the ear, these to the eye; and the subjects were tested singly, not en masse as before.

The elementary time variables are the duration of exposure of the syllable, the intervals between syllables (that is, the time from the beginning of one syllable to the beginning of the next), and the rest, or interval from the end of one complete reading of a series to the beginning of the next reading. As the vacant interval from one exposure to the next is the complement of the exposure with respect to the whole interval, it will not need separate treatment.

Mr. Herrington's work comprises thus three sets of experiments, one for each of the time variables, with records from three subjects in each case. Twelve syllable series were used throughout. Each was read four times under conditions required by the problem, immediately after which, within a specified time, the subject was required to write down as many syllables as he could. Forty-eight series were studied, that is, read silently by each person at each rate. Each day he was given twelve series to learn. These were distributed equally with respect to the different rates and taken in such an order as to compensate as far as possible for practice and fatigue, so as to permit at the end a safe comparison of the records under the different conditions.

The first set of records concerns the value of variations in the time of exposure, or visibility, of the syllable, when the total interval from syllable to syllable remains constant. The exposure was reduced till it seemed barely possible, without practice, to read a series correctly. This exposure was 41σ. The exposure was then increased by doubling so that the duration makes a geometrical series, all but the last, which was erroneously made a little too small for this purpose. The total constant interval from syllable to syllable was 768σ. By subtracting from this the different exposure times, the length of the vacant intervals from the end of one exposure to the next may be obtained. The following table gives the average number of errors of all kinds, per series, together with the probable

TABLE III.

Exposure.	41σ	82σ	164σ	318σ
J. L. M.	13.6 ± .25	12.8 ± .34	13.7 ± .03	13.1 ± .31
G. A. H.	10.7 ± .23	10.1 ± .03	10.7 ± .32	10.8 ± .35
J. H. W.	10.7 ± .23	10.2 ± .23	10.5 ± .19	10.7 ± .22
Average.	11.66	11.03	11.63	11.53

errors of the averages, the latter being calculated from the records grouped into six averages of eight each to compensate for practice effects.

It will be seen that the variations in the exposure appear to affect the results but little. However, a well marked preference was expressed by the subjects for the exposure of 82σ, though the actual results do not indicate any important difference in its favor. It was said to be more agreeable and restful than the others. It is on account of this preference that this exposure is used in the subsequent experiments with other variables. The 318σ exposure was felt to be unnecessarily and somewhat disagreeably long and the 41σ as so inconveniently short as to involve a strain.

The apprehension of a syllable is so nearly purely a preformed apperceptive process that the longer duration of the visual image seems to affect the result but little. In fact the process appears to have a period of its own so that the duration of the objective stimulus beyond a certain point is felt to be disagreeable. The process of apprehension does not end with the exposure; for, as will be seen in the next experiment, the length of the vacant interval before the next exposure affects the results very greatly, but for this the objective stimulus is not needed and is likely to be felt as a source of distraction.

There is still another way, besides through the duration of the visual impression, that we might expect that varying exposure would affect the results, that is by inducing a more or less tense attention according as the syllable must be recognized in a very short or a relatively long time. That this would affect the records favorably or unfavorably, is not impossible. Another set of records would, perhaps, give more marked differences than were obtained this time, especially since the subjects learned so few of the syllables that a difference of a single one represents a large fraction of all they learned and the test could be made more sensitive either by reducing the number of syllables or increasing the number of repetitions. The comment of one subject on the 318σ exposure suggests another possibility, which it would require additional experiments to test. He said this exposure was unsatisfactory because it was too long for one thought of the syllable and not long enough for two. Should the hypothesis implied prove correct, there might be several exposures of a certain periodicity that would appear agreeable, though it does not seem probable that a second or third look would enable the subject to make better records than he would make with the same number of purely mental repetitions.

In the second set of experiments the exposure is kept constant at 82σ, but the interval from the beginning of one syllable

to the beginning of the next is varied. The vacant interval from the end of one exposure to the beginning of the next is, of course, obtained by subtracting 82σ from the total interval in each case. The method and programme of work is similar to that of the preceding experiment. There are 48 records for each average, or a total of 432. The subjects were requested not to repeat the syllables more than once, which they did silently at the time of exposure, and to make an effort to keep the mental processes parallel with the external series given by the apparatus, so that the results obtained might not be due to conscious utilization of the longer intervals for extra repetitions. It was with the variable here considered that the experiments of Supt. Sanders dealt, though with different materials and methods. Below is a table of the average number of errors per series.

TABLE IV.

Total intervals.	384σ	768σ	1536σ
W. W. C.	11.6 ± .27	10.4 ± .19	10.1 ± .34
J. R. P.	9.3 ± .14	8.7 ± .14	6.5 ± .13
U. M.	10. ± .25	7.6 ± .19	5.9 ± .13
Average.	10.3	8.9	7.5

The effect of increasing the intervals is greatly to decrease the number of errors. The short interval is nearly the minimum for persons without special training, but the indications are that an interval longer than any employed would have still further reduced the errors.

In the third set of experiments the rest, or interval, between the end of one reading and the beginning of the next reading of the series as a whole, is the object of investigation. A procedure corresponding with that of the preceding experiments is employed. As before, the table gives the average number of errors per series, of which there were 48 for each average, or a total of 432. The exposure was 82σ, and the interval from the beginning of one syllable to the beginning of the next was 556σ. The subjects were asked to avoid recalling the syllables in the rest period; and two of them employed devices like whistling or humming tunes to enable them better to conform to the requirement.

It is clear that the duration of the rest between readings can, also, greatly affect the results. The length either of the intervals between syllables or of the rests between readings need therefore to be regulated carefully in memory experimentation.

Both longer intervals between syllables and longer rests be-

TABLE V.

Rests.	0	30	60 seconds.
M. A. C.	9.3 ± .34	8.7 ± .19	7.4 ± .23
W. T. S.	9.5 ± .27	7.6 ± .02	6.7 ± .03
M. S.	9.4 ± .03	6.9 ± .37	5.8 ± .17
Average.	9.4	7.73	6.63

tween readings increase the average time between the reception of the impression and the effort to reproduce it. Other things being equal, we should expect this to cause an increase and not a decrease in the number of errors with the longer intervals and rests, since we are disposed to assume that a nervous impression begins to fade away soon after it is received, in case it is left to itself and not further elaborated and connected by attention, which accords with many facts both of the laboratory and of common experience. If this assumption is true, then the advantage of the longer intervals and rests would consist not of greater strength from the independent development of the impression, but of greater strength either from clearer first impressions, or from more adequate association, or from the development of tendencies to recall, or perhaps from still other factors, less known, but like these, favored by a longer time. While it would still be necessary to recognize these factors if this assumption were not true, since they have undoubted value; yet, if the assumption is not true, an hypothesis with regard to the effect of the passage of time upon an impression could be framed that might be a partial explanation of the results. If, for example, the contrary hypothesis were plausible, namely, that an association, like an organ of the body in its development, grew stronger the older it became, then a longer average time between impression and reproduction would be of advantage.

Whether this hypothesis is involved in Jost's law is uncertain, since he emphasizes especially the matter of repetition, and would explain the value of rests between readings by the theory that the repetition of older has a greater value relatively than the repetition of younger associations. Such a specific value might, of course, be due to continued growth of strength of the association with time or to a greater efficacy of the act of repetition itself in the case of older associations. The latter alternative is more strongly implied by Jost's phraseology. If such a peculiar process should actually exist, it is likely that it would be due to a special development in mental evolution. Its general effect would be partly to counteract the disadvan-

tage of forgetting in the case of the associations which experience required us to renew. This might possibly be of sufficient practical importance to make the process subject to natural selection. However, several other factors, whose efficiency is undoubted, need to be taken into account; and such an hypothesis should not be resorted to till these are exhausted.

Of all the errors made by the subjects in the tests for the effect of different exposures, 70% were omissions, 26% were insertions, and 4% were mistakes of order. These per cents vary considerably with the different persons but the distribution of errors for each one with the different exposures is about the same.

With varying intervals between syllables, the per cents of the different kinds of errors are 79.66, 17.33, and 3; and we note here, too, wide individual differences. But there is, in addition, an important difference in the distribution of errors with the different rates, as will be seen in the following table.

TABLE VI.

Intervals.	Omissions.	Insertions.	Mistakes of order.
384σ	39.8	36.1	21.1
768σ	33.5	32.2	30.3
1536σ	26.6	31.7	48.6

The distribution of the mistakes of order, which, however, are only 3% of the whole and so do not greatly affect the general average, varies inversely as that of the omissions. This is true of all three subjects. The distribution of the insertions is not so definite.

It appears, then, that the longer intervals serve especially to enable the subject to fix in mind a larger number of syllables but that the place and connection of the syllables grows less distinct with the longer intervals. We should not have such a result if Jost's law were true of all kinds of associations, including those determining the order; and another hypothesis would fit the facts of the above experiment better, namely, that the longer intervals, through keener attention and longer time for association, permit a better associative apprehension of the syllables. Even if definite mnemonic words are not suggested, bits of words, familiar letter sequences, or other forms of more or less conscious incorporation with existing neural paths may be brought into action if there is time enough. If this hypothesis is true, the explanation of the value of the intervals with the nonsense syllables would be similar to that given for associable and particularly dyssociable words.

In the experiments with rests between readings the distribution of errors is, omissions 79.3%, insertions 17%, and mistakes of order 3.7%. The two subjects (W. T. S. and M. S.) who show the most marked effects from lengthening rests show also an inverse relation between omissions and insertions, corresponding in degree with that noted above. The third subject (M. A. C.) had only one per cent. of mistakes of order. His method of memorizing seemed to be to form a visual image of the whole series and he appears to have forgotten both the syllables and their order at about the same rate.

VI.

The relation of these experiments to those of others has already been considered in Sections II and III, as far as apparatus and technique are concerned; but there remains the task of discussing briefly also the place of the problems and results. The possibility of such investigations is suggested in the orderly procedure employed by Ebbinghaus; moreover, he made the following observations, which have been the starting point for several other investigations in this field. In a series of experiments he learned 12 syllable series on one day and then relearned the same series on the three succeeding days. The average number of readings required for an errorless repetition was 17.5 the first day; 12, the second; 8.5, the third; and 5, the fourth. In another experiment he continued reading and repeating 12 syllable series longer than was necessary for the first errorless repetition, in fact till he reached a number about four times as great, that is, a total of 68. On relearning the series after 24 hours, he found that he, nevertheless, needed 7 readings. On comparing the two facts it is found that the final relearning in the first case was preceded by 38 readings and repetitions, distributed over three days; in the second, by 68 taken all on the day before. This appears to be the first observation on the value of rests between readings of series of syllables.

On the value of intervals between syllables, the first observation published seems to be that by Miss T. L. Smith in her study of "Muscular Memory," though perhaps intervals between readings as well as syllables are included. In these experiments ten syllable series were exposed to view for twenty seconds for the subject to study, immediately after which he was given 70 seconds to record what he could recollect. The subjects were at liberty to read at whatever rate they pleased and they selected quite different rates, one reading the series through once or twice, another four or five times, the rest being between these extremes. The subjects that read most slowly were found to have made the best records. This might be due

to personal differences in retentiveness, though there is considerable probability that the difference in rate contributed largely to the result.

With regard to the effect of variations in the exposure of syllables, the apparatus so far employed by others has not permitted accurate experimentation, since changes in exposure have also involved some other variables as well.

On other aspects of the problem considerable material has accumulated. Attempts have especially been made to study the related question of economy in memorizing. Thus, Ebbinghaus reports experiments in which he memorized stanzas of Schiller's translation of the Æneid at the rate of 200, 150, 120, and 100 iambics per minute, and found he learned the same number of lines in 138, 148, 160 and 180 seconds, respectively, which shows that the amount of time required was inversely as the speed. On relearning these lines, presumably at a single rate, twenty-four hours later, he found that 90, 89, 96, and 99 seconds were required, which shows with regard to the permanence a slight difference in favor of the more rapid rates. The question of economy would, of course, also require the consideration of the degree of exhaustion produced by the different rates; and from this point of view the more rapid rates might not be preferable. It will be observed that a greater number of repetitions is required with the rapid than with the slow rates to accomplish the same result. Wherefore we may infer a general correspondence with the results reported in this paper, since repetitions at a slower rate have greater value. However, there may be a still more intimate correspondence with the results for the acquisition of easily associable material discussed in Section IV. The intervals from the beginning of one to the beginning of the next iambic were .3, .4, .5, and .6 seconds respectively for the different rates. The number of repetitions of the lines at the respective rates is therefore proportionate to 46, 37, 32, and 30. If we assume that, when the lines are learned, that they are learned to the same extent with each rate, then the associative value that must be assigned to each interval is nearly proportional to the logarithm of the interval, the products of the number of repetitions and the logarithms of the intervals being proportional to 219, 224, 224, and 233. This fact suggests a correspondence with the law stated in Section IV, that the rate of acquisition varies as the logarithm of the intervals between the items of easily associable material, and thus extends its application to other material and at the same time makes it somewhat probable that it is true not simply for one single repetition, as in the experiments of Table IV, but also of a considerable number of repetitions, as in these experiments of Ebbinghaus.

The experiments of Jost deal with the value of the distributions of readings and repetitions in memorizing, the problem proposed by the early observations of Ebbinghaus, which Jost's results in part serve to confirm and in part to extend. He makes use of two methods, at first the complete memorizing, then the right associates method, and finally the two in conjunction, thus obtaining records whose difference makes the point of chief interest in the paper. By the complete memorizing method he finds with two subjects that ten readings of nonsense syllable series on each of three successive days makes the memorizing of the series on the fourth day easier than do thirty readings on the day immediately preceding, though the difference is small. By the right associates method he finds with two subjects, when twenty-four repetitions are distributed equally on 3, 6 and 12 days respectively, that the most extended distribution, that of two repetitions a day, gives the best results. He formulates and would explain his own results, and the corresponding results of Ebbinghaus as well, by the law that the repetition of an old has relatively a greater effect than the repetition of a young association. The possibility of applying Jost's formula in the case of our results has already been considered in section V.

With the complete memorizing method in the study of these and many other problems a repetition of old associations is involved in the final test, which is not the case with the method of right associates, for here the subject is merely called upon to reproduce associates. If both methods are employed together to test memory for series learned a longer or shorter time ago, the complete memorizing should, according to the law, give relatively better records with the older series, an hypothesis which experimental results from two subjects verify. The difference in the results by the two methods could be explained by Jost's law, but also by the hypothesis that it was due, not to the greater value of repetitions of old associations, but rather to a more rapid decrease of the voluntary revivability of the syllables, which is the thing tested by the method of right associates, than of retentiveness. It is a matter of common experience that the ability to revive, or recall, disappears quickly and long before other evidences of some degree of retention, such as the ability to recognize the object if it is brought up in some other way; and Müller and Pilzecker have shown that, when the same number of right associates are recalled in the case of older and more recently learned series, a longer time is required with the older, indicating greater difficulty. One other thing should be noted. Jost deals only with rests between readings of series; but the effect of longer intervals between syllables seems to be the same as that of longer rests. If the

effect is due to the greater elaboration of the same process in both cases, which is not certain, but seems probable, then we have in experiments of Section IV such favorable results as Jost believed to be due to the repetition of old associations in a case which involves no repetition of old associations, but merely a longer time for assimilation.

The part of the work of Lottie Steffens which especially concerns our problems consists of some experiments on the effect of different distributions of six readings within the same period of time. The series were read from a drum, which revolved 12 times in 78 seconds. The most expanded distribution of the series was obtained by reading them every other revolution of the drum; the next grade, by having three readings, then an interval of three revolutions, then three readings and again an interval of three revolutions; the last grade, by having all six readings at first, then an interval of six revolutions. It will be observed that the readings, except in the first case, are more or less massed, which leads Miss Steffens to introduce the following explanation of the better results she obtains with the more widely distributed order. In proportion as the readings are massed, the strength of the associations for the time being is greater; but the stronger the associations the greater is the absolute loss of strength by the time the series in these experiments were to be completely memorized. Since, according to Ebbinghaus, the loss is proportional to the number of readings, the resultant of massing six readings at the beginning is to make the foundation for the complete memorizing of the series not so strong as in the other cases. This explanation would apply with such an arrangement of readings as is employed by Miss Steffens, that is, with the massed readings placed at the beginning of the period; but it would not apply when the massed readings are placed at the end, as in the case of the experiments of Ebbinghaus and Jost, in which, nevertheless, the expanded distribution proved more advantageous. If, on the other hand, the loss of strength were relatively greater to a sufficient extent with the massed than the distributed readings, this type of explanation might be generally valid; but of this there is no certain evidence, since in experiments which might give information on this point there is always the very probable alternative, as an explanation of the differences observed in favor of the distributed readings, that the later numbers of massed readings do not have so great a value as the earlier.

Ogden deals directly with the problems under consideration. His work comprises six parts, the first four dealing with memorizing nonsense syllables, the last two with memorizing poetry. The apparatus employed was similar to that of Müller

and Schumann, the syllables being presented back of an aperture by a kymograph drum. The different rates were obtained by changing the rate of rotation of the drum and in experiments with constant intervals between readings, partly by spacing the syllables. Observations on varying exposure and rests between readings were inconclusive, as other variables entered in. The chief groups of experiments deal with the effect of varying the interval between syllables. In the first group, the time from syllable to syllable varied from 2.6 to .9 seconds; in the second, from 1.026 to .325, each in five successive steps. The exposure varied simultaneously in both sets from .705 to .289 seconds, the rests between readings remaining constant at 2.8. Of these two variables, that which affects the result the most is probably the rate of succession. To ascertain the effect of the different rates upon the permanence of the impressions as well as upon learning in the first instance, the series were relearned, usually after fourteen days; a difference in this respect was, however, not clearly demonstrable. The most general result is that with the quicker rates more readings are required but not so many but that the series may be learned in less time than with the slower. Thus subject K required from 12 to 20 and from 7 to 15 readings, respectively, in two experiments in which the intervals varied from 2.6 to .9; and from 13 to 33, respectively, when the rate varied from 1.026 to .325. However, the total time required shortened from 394 to 263 and from 222 to 200 and from 214 to 213.

Ephrussi's investigations fall into two divisions, the first dealing with learning by whole or part, the second with the effect of variation in the rate of memorizing. Ebbinghaus' experiments upon the effect of varying the rate of learning verses of Schiller's translation of the Æneid is repeated with three subjects and with results that agree roughly with his. However, the most interesting fact brought out by Ephrussi's work is what he calls the paradoxical result, namely, that the right associates method gives the best records with the slowest rate, while the complete memorizing method does the reverse, in tests with nonsense syllables. Series of syllables were read at different rates for a given period, at the end of which some were memorized and some were tested by the method of right associates. It is in this experiment that the paradoxical result appears, for the series are memorized more easily but give less right associates after the rapid readings. The chief reason assigned is one he verifies experimentally, namely, that the decrease of the number of right associates takes place more quickly after the rapid than the slow readings. The complete memorizing is done by continuing the readings of the preparatory period, while an interval of five minutes occurs before the

test for the right associates, which would permit the more rapid reduction succeeding the quicker rate to produce the paradoxical result. The difference in results with these two methods by both Ephrussi and Jost gives a glimpse of a greater complexity and independence of processes than might at first be supposed to exist.

Ephrussi employed the kymograph apparatus of Müller and Schumann, but in the more recent experiments of Reuther at Leipzig a new type of apparatus, that developed by Randsburg and Wirth is brought into use. As was stated in the discussion of apparatus, the syllable is presented in this not by a continuous but by a step-wise motion of the disc or drum, resembling that used in our experiments, except that it does not have means for the independent variation of the exposure and the rests between readings. Thus, in his experiments upon "the amount retained as a function of the duration of exposure," he does not refer to a study of the effect of varying the exposure of a syllable while the interval between syllables remains constant, as in our experiments. This experiment of his corresponds rather with our experiment upon the effect of different intervals between syllables. For his items are written on every other sector of the Wirth apparatus, which moves forward uniformly a sector at a time. By exposure he means the time a sector bearing a number is present back of the aperture. This is followed by an empty sector, which remains the same length of time, to be in turn succeeded by another number, his "*Expositionsdauer*" being thus equivalent to one-half of the interval between the numbers. He thus has two variables, of which the total interval between the numbers is doubtless the more important. His experiment does not wholly correspond with ours, since in ours the exposure is kept constant. The total intervals employed by Reuther were from one-half to three seconds in length, with five intermediates between the extremes. Two of his three subjects show that the lengthening of the interval is advantageous; with the third, the effect is not so definite as he has at first better then poorer records, with the optimum at one second.

The memory material and the methods must be kept in mind in comparing these results with others. The items were four place numbers, which were read one or more times and then shown to the subject again with the requirement that he should indicate which ones he recognized as having seen before. The intervals between reading and opportunity for recognition was in this case five minutes.

With similar materials and methods, Reuther also made experiments with two subjects upon the rest period between readings, which corresponds with the last of our experiments.

The rests he employed were 4 seconds and 1, 2, and 5 minutes. There is a slight indication that there is a critical period up to which the rests are increasingly beneficial and beyond which this advantage diminishes. Such a critical point has not been observed in other experiments, though rests have been made very long, as in the case of Jost's experiment in which 24 readings were distributed over 12 days and the widest distribution, that of two a day, found to be the best.

VII.

Even with the simplification introduced by experimental conditions, the problem is evidently complex; and it is desirable, as far as we can do so, to attempt to ascertain the relative scope of the different factors involved. As to what they are, as the historical survey shows, several theories have been proposed, usually to account for certain experimental results, and so often not adequate for all. If true, they cannot all be complete but will rather be supplementary. The different factors suggested by these theories and by other possible explanations may be classified into four groups; first, conditions aiding or obstructing the reception and association of the impression; which we will call the apperceptive factor; second, changes and relative variations in retention; third, modifications in the recalling of impressions; fourth, general conditions, such as fatigue or a general organizing activity.

As has been stated with some detail in Sections IV and V, it is the first of these factors, the apperceptive, that seems especially concerned in the production of the results here represented. The material which consisted of simple letters, nonsense syllables, dissociable and associable words, makes a series of increasing apperceptive complexity. The relative ease with which these can be memorized and the effect of the varying intervals seems to be proportional to the amount of apperceptive apprehension of the material and its connections. Even in the case of the letters and nonsense syllables, some evidence was given that the advantage of longer intervals was due to associative processes. While general vigor and fatigue may make the neural disposition more or less strong, they certainly in large part bring about the results they do have by extending or restricting apperceptive processes. The persistence of an impression, or its tendency to maintain itself in consciousness for a time, is also a more or less automatic activity that must be taken into account, as must also the supplementary voluntary attention to the impression. One effect of both of these processes is to vary the degree of apperception. Whether there is any further effect, as far as memory is concerned, can probably neither be asserted nor denied, at present.

That marked changes in the retention of an impression occur as the interval between its reception and reproduction increases, is well known, the most general feature being represented by Ebbinghaus law of inverse logarithmic decrease of strength. As has already been stated, Jost, Steffens, and Ephrussi would explain some results in this field by making certain hypotheses as to changes in retention. Some objections to the application of Jost's law to our results have already been stated; but it may very well be required that the explanation preferred should be tested by his results upon the effect of different distributions of readings, as well as by our own. The same may be said of the theory of Steffens. The underlying premise of both these explanations, that readings or repetitions, whatever their number, up to a certain limit, which in their experiments need not exceed the number necessary for the first perfect repetition, have an equal, or nearly equal, value, is, as far as they have been tested, the least certain of the original results of Ebbinghaus. Each reading may, in fact, have a decidedly greater value, if it is well spaced off from others, than if it is one of a considerable number made in immediate succession, primarily because a higher degree of assimilation could take place each time. The interpretation of the results presented in this paper would imply that this is the fact.

On the other hand, that changes in retention or recall are the cause of the differences in the results obtained by Jost and Ephrussi in the simultaneous use of the complete memorizing and right associates methods described in Section IV seems probable. At least, these differences develop with the lengthening of the time between the impression and its reproduction; and in the case of the results of Jost, if his hypothesis of the relatively greater value of the repetition of old than young associations be regarded as improbable, the effect should perhaps rather be ascribed, as was suggested, to a modification of reproduction than retention. With regard to the observation of Ephrussi that the right associates decreased more rapidly with time if the series were read at a rapid rate, a plausible explanation would connect this also with changes in retention or recall, namely, that a qualitative difference was produced by slow and fast rates, so that in the first case there was more of an incorporation with old and permanent associations while in the second it was more a matter of immediate sense memory, which would disappear much more rapidly. While the results observed would be primarily due to differences in the degree of apperception, the immediate cause would be the relative difference in the retention, or rate of forgetting. However, what the effects of different rates upon retention may be, is not wholly clear, for the few results of other investigators are not conclusive regarding this point.

The influence of possible modifications in the process of recall have apparently not been considered in the various theories regarding the effect of rate in memorizing. As has been suggested, such a modification may account for certain results.

In still another way the reproducing processes may play a part. Miss Smith has shown that repressing or executing the verbal or manual expression of the ideas to be memorized will produce a difference of 15 to 20% in favor of the expression. This expression, which may be regarded as the first recall or reproduction, comes last in reading; and may, with rapid rates, be partly repressed, leaving the reproducing tendencies undeveloped and having an effect comparable with that found by Miss Smith with voluntary repression. Definite observations as to the influence of this factor have not been made, and it is proposed merely as one possibly present in varying degrees with the rapid rates, and serving not merely to create a disposition to recall, but also to keep the idea present for more complete apperception.

With regard to the theory of the existence of a more or less unconscious organizing process continuing some time after the impression has been received and necessary for its permanence and revivability, our results afford some evidence. Our subjects were requested to read the syllables when presented, but to avoid voluntarily recalling them, however much time might be at their disposal for so doing. In experiments of Table V two subjects employed devices to distract the attention during the periods of rest. The fact that the influence of longer intervals and rests is, nevertheless, very marked, makes it somewhat probable that the processes involved, except in their inception, are automatic. With regard to their continuance and dependence upon attention, we must note that the rapid displacement of one impression by the next interferes greatly with memorizing; the organization would, therefore, seem to take place chiefly, perhaps wholly, while nothing else in the shape of a definite impression was before the mind, though there can be general distraction. The variation of the results throughout with the degree of possible apperception suggests that it is this mode of organization that is taking place. The mode of organization might, of course, be of a wholly different character, perhaps not associative at all, but rather like the setting of cement or the adaptation of a plant to a certain curvature, which would also vary with the time allotted. But, however much such figures may be used in regard to the operations of memory, no definite evidence has yet been presented that such processes take place.

That fatigue, in its triple character of auto-intoxication and reduced cell energy and nervous tension, may greatly affect

memorizing ability is certain ; and it has probably more generally than anything else been supposed to be the explanation of the difference in value of the massed and widely distributed readings. It is necessary to distinguish from fatigue obstructions resulting from the limits of the memory span, from the persistence of impressions or the interference of associations, or from adaptation, or from other normal processes of the mind. When this is done, the explanatory value of fatigue will be found to be quite limited. In these experiments the effects of general fatigue were counteracted, as far as the averages are concerned, by the programme of work ; and that it should seriously enter into the results of a single record, does not seem probable, especially since other clearly efficient factors are in evidence.

In so far as these experiments bring us into a closer view of the general, practical problems involved, they serve especially to emphasize the predominant importance of apperception in memorizing and the value of sufficient time for its development.

The number and intensity, and so permanence and revivability, of the associations formed may be regarded as a quantity; and a solution of the problem of time economy in memorizing may be attempted with the aid of the formula for the rate of acquisition, proposed in Section IV, and from other data. The general statement of the problem will be, through what means can the greatest amount of apperception of material take place in a given time; though only the effect of a greater or less number of repetitions will be considered. The amount of apperception is a function of the interval between items and also of the number of repetitions; and if it varied directly and equally with each, there would be compensation so that the result of any practicable number of repetitions in a given time would be the same as that of any other, since the intervals and repetitions vary inversely. As a matter of fact, apperception appears to vary as the logarithm of the interval; and, if we assume that it continues to vary at the same time in simple ratio with the repetitions, it will be greater in amount the more numerous the repetitions, within certain limits. If n, $\frac{n}{2}$, $\frac{n}{3}$, represent the number of repetitions in a given time, t, 2t, 3t will be the corresponding intervals, and the amounts of apperception will be proportionate to n (log. t), $\frac{n}{2}$ (log. 2t), and $\frac{n}{3}$ (log. 3t) etc., quantities which decrease rapidly at first then more slowly.

It is conceivable that the value of successful repetitions would so change as to compensate more or less for the relatively greater effect of the shorter intervals, but there is no evidence that this occurs completely, but rather evidence to the contrary, as has been indicated in the review of the investiga-

tions dealing with this problem; so that on the whole it is probably possible to memorize more quickly with the more rapid repetitions.

Nevertheless, there is great difference in the relative value of repetitions and intervals with different kinds of materials and also with different types of memory, so that a high degree of uniformity in this respect cannot be expected.

BIBLIOGRAPHY.

BURNHAM, W. H. Retroactive amnesia. *Amer. Jour. of Psy.*, July, 1903, Vol. XIV, pp. 382-396.

EBBINGHAUS, HERMANN. Grundzüge der Psychologie. Leipzig, Vol. I (1st ed.), 1902, 694 p.; (2d ed.) 1905, 732 p.

——— ——— Über das Gedächtnis; Untersuchungen zur experimentellen Psychologie. Leipzig, 1885. 169 p.

EPHRUSSI, P. Experimentelle Beiträge zur Lehre vom Gedächtnis. Zeits. für Psy. und Physiol. der Sinnesorgane, 1904, Vol. XXXVII, pp. 56-103; 161-234.

JOST, ADOLF. Die Assoziationsfestigkeit in ihrer Abhängigkeit von der Verteilung der Wiederholungen. Zeits. für Psy. und Physiol. der Sinnesorgane, 1897, Vol. XIV, pp. 436-472.

MÜLLER, G. E. and PILZECKER, A. Experimentelle Beiträge zur Lehre vom Gedächtniss. Zeits. für Psy. und Physiol. der Sinnesorgane, Ergänzungsband 1, 1900. 288 p.

MÜLLER, G. E and SCHUMANN, F. Experimentelle Beiträge zur Untersuchung des Gedächtnisses. Zeits. für Psy. und Physiol. der Sinnesorgane, 1893, Vol. 6, pp. 81-190; 257-339.

OGDEN, R. M. Untersuchungen über den Einfluss der Geschwindigkeit des lauten Lesens auf das Erlernen und Behalten von sinnlosen und sinnvollen Stoffen. Arch. für die ges. Psy., 1903, Vol. II, pp. 93-189.

REUTHER, FRITZ. Beiträge zur Gedächtnisforschung. Psy. Studien, 1905, Vol. I, pp. 4-101.

SMITH, THEODATE L. On muscular memory. *Amer. Jour. of Psy.*, July, 1896, Vol. VII, pp. 453-490.

STEFFENS, LOTTIE. Experimentelle Beiträge zur Lehre vom ökonomischen Lernen. Zeits. für Psy. und Physiol. der Sinnesorgane, 1900, Vol. 22, pp. 321-382.